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INVESTIGATION OF THE HEAT TRANSFER BETWEEN THE GAS AND CASING IN THE AREA OF THE INTER-VANE CHANNELS OF THE STATOR AND GUIDE VANES OF TURBINES

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As was already noted in [1 — 3] et al., the heat transfer between the front surface of the inter-vane channels of turbulent cascades may differ from the heat transfer of a flat plate under the same flow conditions (Re, M, etc.). Recommendations on calculating the coefficient of heat transfer from a gas to the front surface of the inter-vane channels differ greatly, and have been obtained from studies of a comparatively small number of turbine cascades. Theoretical solutions [4], etc., based on calculating the three-dimensional boundary layer in the presence of longitudinal and transverse pressure drops, are still inadequate. /62*

The purpose of this article is to perform an experimental study and to generalize the experimental data on the heat transfer between a gas and a turbine casing in the area of the inter-vane channels of stators and the guide vanes.

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*Numbers in the margin indicate pagination of original foreign text.

Experimental Stands and Objects Studied

The experiments investigating heat transfer were performed on two gas dynamic stands: on an experimental air turbine [5], and on a stand for blowing through flat turbine cascades [3]. In the first case, the heat transfer was studied on the inner and outer casings in the region of the turbine stators. The basic characteristics of the cascades are given in the table (cascades 1 — 4). The table also gives the characteristics of other cascades (cascades 5 — 8) studied previously by the Kuybyshev Aviation Institute (KAI) [3, 6].

Two methods were used to determine the heat transfer coefficient: a calorimetric method and the method of the regular regime of the first type [7]. The calorimetric method is described in [3]. When the regular thermal regime method was used, cylindrical copper inserts were placed in the casing on the front surfaces of the inter-vane channels. Figure 1 shows the way these inserts were located in cascades 1 — 3. This figure also shows the manner in which the inserts were embedded. As may be seen from Figure 1 (cross section A — A), the copper inserts 1 were placed in Teflon, heat insulating stoppers 4. A copper compensation ("safety") ring 3 is placed between the insert and the stopper. This ring is heat insulated from the insert by a Teflon bushing 2. This manner of embedding the insert created the conditions necessary for producing a regular thermal regime of the first kind in the insert.

The study [3] gives the basic measurements, the method of performing the experiments, and the characteristics of processing the experimental data based on the calorimetric method.

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Cascade No.	Cascade type		Chord mm	Width* mm	Input angle	Output angle	Step* mm	Sg criteria [8]	Research method
1	Ring	Periphery	57,14	40/0,7	90°	21°	40/0,7	4,11	Regular regime method
		Root	57,14	40/0,7	90°	19°	30/0,525	5,55	"
2	Ring (periphery)		35	23/0,658	90°	19°	30/0,858	4,09	"
3	Flat		180	110,3/0,614	90°	15°20′	145,1/0,807	4,6	"
4	Flat		135,1	132,75/0,98	34°30′	29°	76,4/0,565	2,15	Calorimetric method
5	Flat [3]		135,65	127,45/0,94	20°	18°30′	74,15/0,547	1,358	"
6	Flat [6]		30	26/0,867	57°	36°	20/0,668	1,88	Regular regime method
7	Flat [6]		37	34/0,92	55°	33°	20/0,54	2,39	"
8	Ring [6]		40,5	39,15/0,968	34°20′	30°40′	27/0,667	1,633	"

*The relative values of the width and the step of the blade in fractions of the chord are given as fractions.

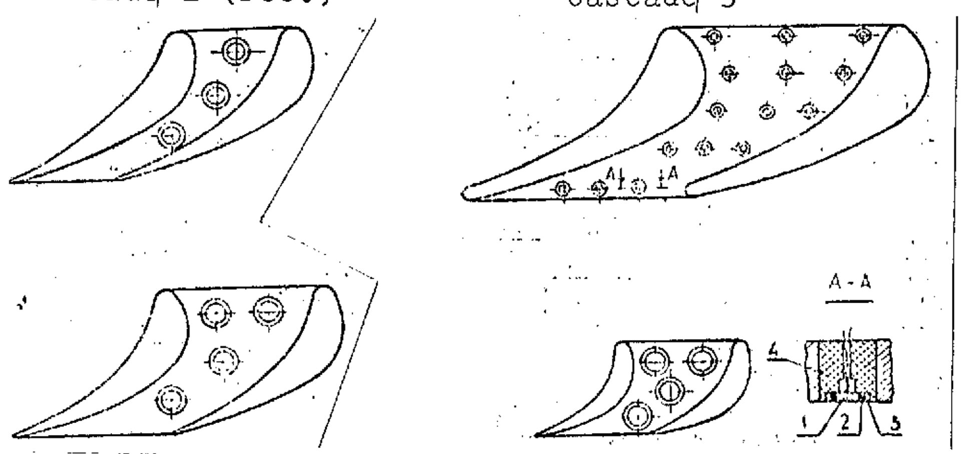

Figure 1. Location of the inserts on the front surfaces of cascades 1, 2, and 3.

When the regular regime method is used, after the equipment /64
has reached a stationary regime, a small amount (approximately 0.5 — 1% of the air consumption) of cooled liquid (water or alcohol) is injected into the air stream. After the surface being studied and the insert are cooled by 10 — 15° K, there is an abrupt detachment of the liquid; starting at this time, the insert change in temperature with time is determined by means of an electronic, semiautomatic EPP-09M potentiometer. The experiments also measured the braking pressure before the cascade, the static pressure at the input and at the output of the cascade, and the braking temperature in front of the cascade. In experiments on a turbine, the static pressure behind the stator was measured in the casing both at the root and the peripheral surfaces of the inter-vane channels. In cascade 3, the distribution of static pressure was also measured over the contour of the vane profile and in the casing in the region of the inter-vane channel. The place where the static pressure was measured in the casing rigorously corresponded to the location of the inserts (15 measurements in all). For greater reliability, all the measurements were repeated in each regime several times.

When processing the experimental results using the method of regular regime, the local values of the heat transfer coefficient were calculated according to the following formula [7]

$$\alpha_x = m\frac{c \cdot G}{F \cdot \psi},$$

where c is the specific heat capacity of the insert material; G — insert weight; F — surface of the insert in the air stream; ψ — coefficient for insert temperature field variation; m — insert heating rate.

The average (over the front surface of the inter-vane channel) heat transfer coefficient was calculated as the arithmetic mean of the local heat transfer coefficients α_x. The results of the experiments were generalized in the similarity criteria, calculated with respect to the parameters at the input and output of the cascade. The determining dimension was assumed to be the profile chord, and the determining temperature was the static temperature before or behind the cascade. The gas density was calculated from the static pressure and the static temperature before or behind the blade.

All of the experiments were performed with a zero angle of attack for the flow at the cascade input.

Experimental Results

Figure 2 gives the results of experiments on the average heat transfer coefficient (in the coordinates lg Nu - lg Re_{av}) in the casing in the region of the front surfaces of the inter-vane channels of eight cascades, whose characteristics are given in the table. Here

$$Re_{av} = \frac{1}{2}(Re_1 + Re_2),$$

where Re_1 and Re_2 are the Reynolds numbers calculated from the parameters at the cascade input and output. For purposes of comparison, the dashed line in this figure gives the heat transfer in the case of the turbulent regime for flow around a flat plate.

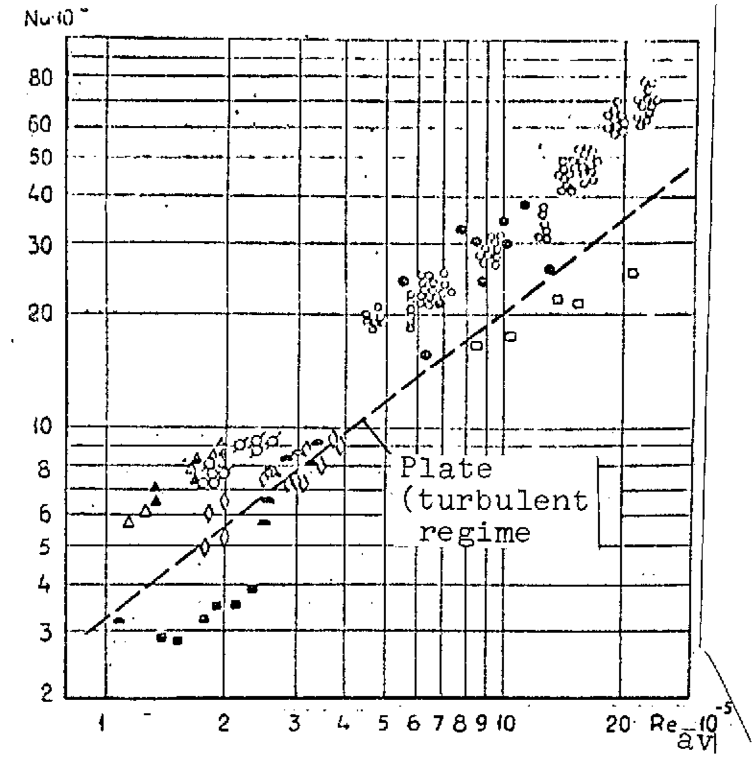

Figure 2. Results of experiments on the average coefficient of heat transfer from a gas to the casing in the region of the front surfaces of the inter-vane channels.

— cascade 1 (outer casing); — the same (inner casing); — cascade 2 (outer casing); — cascades 3, 4, 5, 6, 7, and 8, respectively.

It may be seen that the experimental points are located both above and below the curve for a flat plate. In blades with a small reactivity (cascades 4 — 8), the experimental points are /65 located far above the heat transfer on the plate. This may be primarily explained by the transverse pressure gradients which produce intense flow of the gas from the concave surface on the back edge. In the region of the stator vanes, the experimental points are close to, or even below, the curve for the heat transfer on a flat plate. This may be explained by the transverse pressure gradients which are smaller than in the region of the

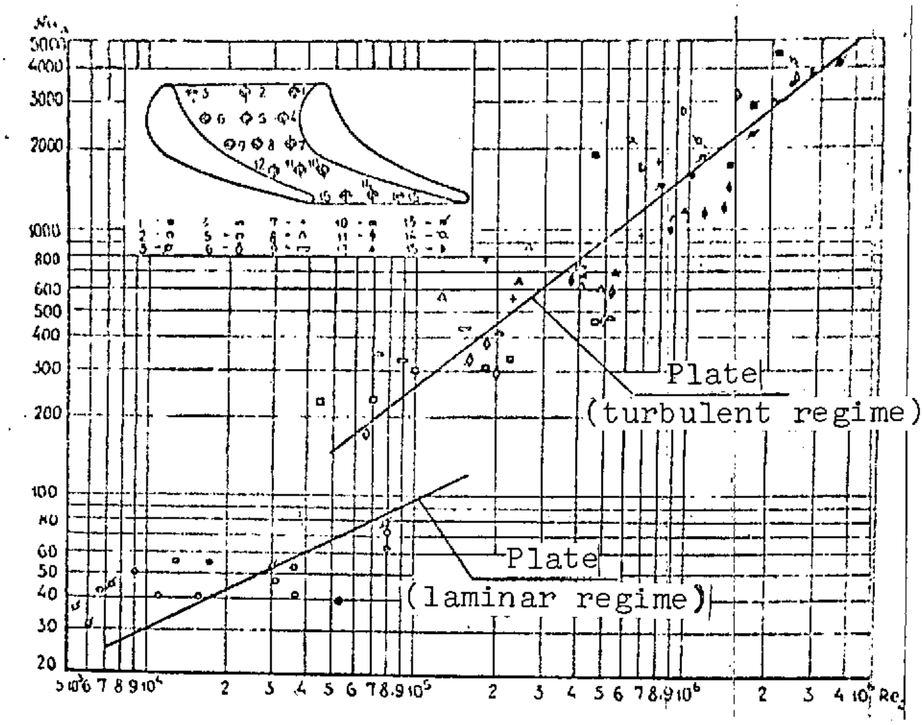

Figure 3. Results of experiments on the local coefficients of heat transfer from a gas to the casing (front surface of the inter-vane channel) for blade 3.

working cascades. In addition, there may be a laminar flow regime in the boundary layer in stator vanes at the input of the inter-vane channel. This is illustrated in Figure 3, where the results of experiments (in the coordinates lg Nu_x - lg Re_x) on the local heat transfer coefficients on the front surface in cascade 3 are given. Here

$$Nu_x = \frac{\alpha_x \cdot x}{\lambda}, \quad Re_x = \frac{w_{xt} \cdot x}{\nu},$$

x is the distance along the streamline from the input to the inter-vane channel to the location of the insert in the casing; w_{xt} — local theoretical velocity (calculated from the static pressure measured on the front surfaces). It follows from Figure 3 that the experimental points for the input section of the inter-vane channel are located below the dependences for the local heat transfer coefficients of the flat plate in the case of a laminar flow regime in a boundary layer, and the remaining points are close to a flat plate for a turbulent flow regime.

Comparing the results of experiments obtained for different /66 cascades we may note the great difference between the heat transfer in cascades of differing geometry. Strictly speaking, it is not valid to extend the results of experiments to geometrically dissimilar cascades. However, with a certain approximation the influence of the basic geometric parameters of the cascade upon the heat transfer from the gas to the casing in the region of the stator and guide cascades, may be calculated by the S_g criterion [8], which takes into account the flow rotation in the cascade:*

$$S_g = \frac{\sin \alpha_{og}}{\sin \alpha_1} \sqrt{\frac{2 \cdot b}{t \cdot \sin(\alpha_{og} + \alpha_1) \cdot \cos^2 \frac{\alpha_{og} - \alpha_1}{2}} - 1}.$$

Here α_{og} is the geometric input angle to the cascade; α_1 — flow output angle from the cascade; b — width of the cascade; t — step of the cascade. The results of this generalization for nine cascades are shown in Figure 4. As may be seen, the majority of the experimental points within an accuracy of ±13% are located close to the following relation (solid line):

$$Nu = 0.065\, Re_{av}^{0.8}\, S_g^{-0.54}$$

*When calculating the heat transfer to the outer casing, we used the cascade geometry on the periphery, and for the inner casing — at the root of the cascade.

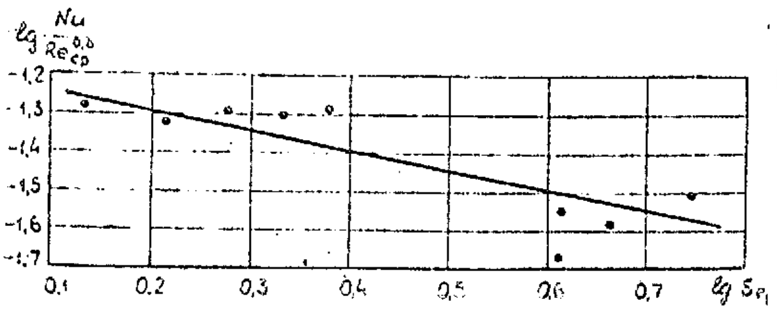

Figure 4. Generalization of experimental data on the heat transfer between a gas and turbine casing in the region of the front surfaces of the inter-vane channels.

The formula may be applied for stators and guide cascades (S_g = 1.3 — 5.5) when Re_{av} changes from $1.1 \cdot 10^5$ to $2.3 \cdot 10^6$, M_2 — by no more than 0.9, and when the temperature factor changes from 0.85 to 1.

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16. Abstract

An experimental study is made of the heat transfer between a gas and a turbine casing in the inter-vane channels of stators and guide vanes.

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